Product modelling in the steel construction domain

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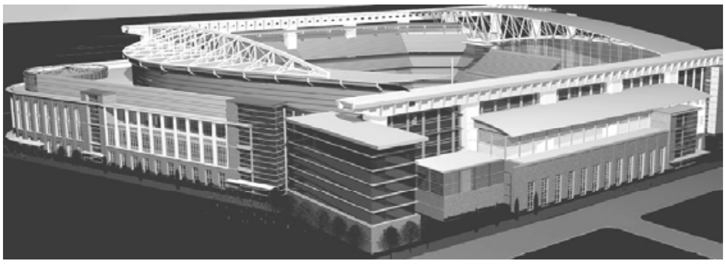
Summary

The complexity of the relationships between the actors of a building project requires high efficiency in communication. Among other things, data sharing is crucial. The exchange of data is made possible by interfaces between expert programs, which rely on product models. The latter are neutral standards with formal definitions of building objects and their attributes. This paper deals with the state of the art and the research activities concerning product models in the steel construction domain and the advantages provided by this technology for the sector.

1 Introduction

In the actual economic environment, the A/E/C Domain is ruled by a strong pressure of time, cost and competition. To raise its efficiency, specific computer applications were developed in the last 20 years to support nearly all occurring tasks. In the steel construction domain, the use of computer assisted methods is particularly pronounced because of the high grade of prefabrication and automation. Software tools for electronic tendering, awarding and invoicing, computerized numerical control of the production machines, but also 3-dimensional object-oriented CAD and structural analysis systems are part of this. Those applications generally fall back on common basic information, e.g. building geometry, and thus the next step of rationalisation is the ability of sharing and exchanging data. In this way double acquisition is avoided, time and money are saved, possible sources of error are reduced. In regard to the large number of partners involved in a building project – Figure 1 –, the impact of this kind of optimisation is obvious. Compatibility between two programs can be reached directly by specific bilateral interfaces. But, because of the large number of actors, the variety of the used software and its developing companies, this method cannot be applied to link all applications over a whole industry domain. A platform-independent, overall approach is required. This is the idea of product models.

Figure 1



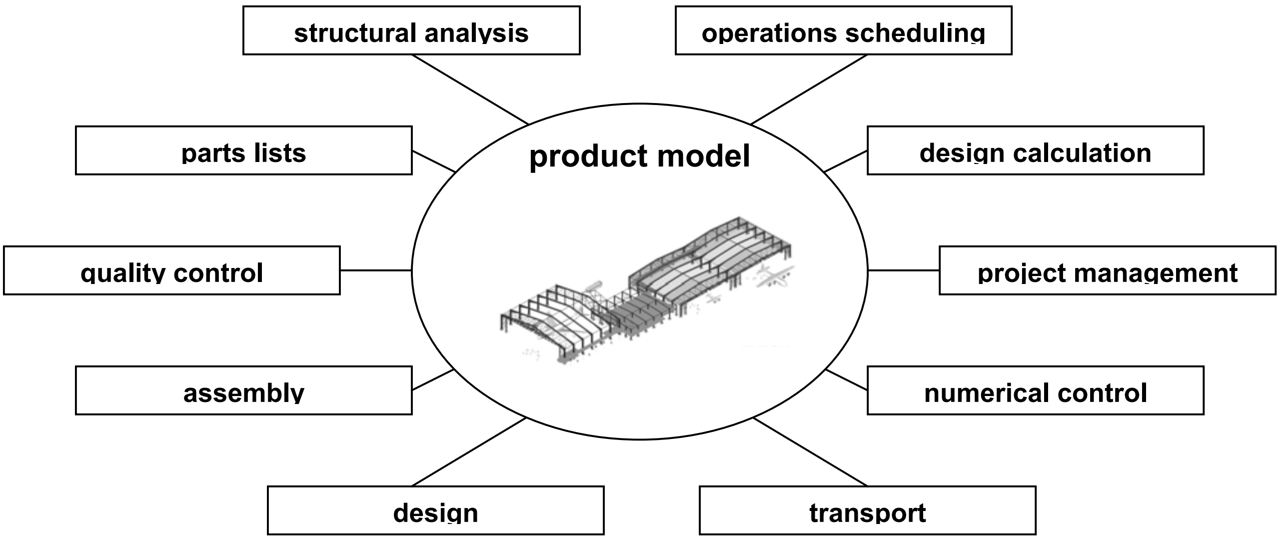
tasks and partners in a building project

2 Product models

2.1 Concept

A product model is a neutral standard which provides a terminology for common objects of a defined area of activity and their attributes. It has a global approach, i.e. it covers the application fields of all used software. For each sub-domain partial data models are defined and then combined in the product model. The principle is shown in Figure 2 by the example of steel construction domain. At this point, it shall be emphasised that a product model is solely a formal definition of objects and neither generates nor manages data. Hence software developers have to implement the interface, i.e. link the objects of their specific applications with the corresponding neutral entities of the product model. To obtain a large implementation, the exchange standard should be publicly available.

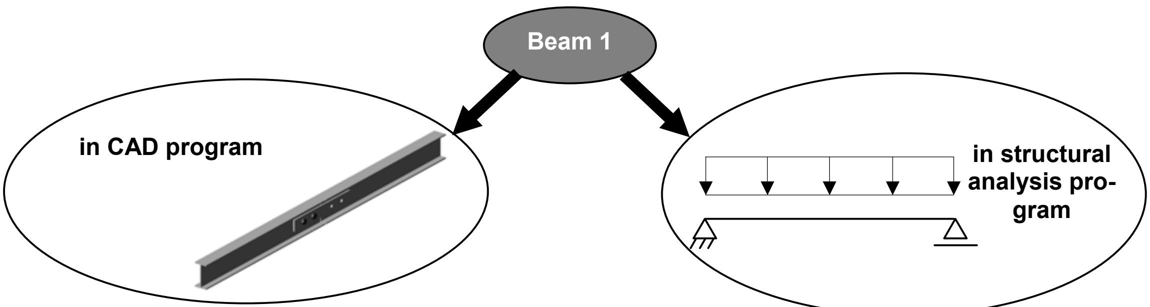
Figure 2



Principle of a product model by the example of steel construction domain

The overall approach of the product model implicates that all possible attributes of an object which might be exchanged must be covered. For example the formal description of a steel beam must include its geometry but also structural information, materials, machining, sub-assembly specifications, etc. Each used application will only be able to handle the information contained in an exchange file which is relevant for it, i.e. it has is own “view” of an object. To continue our example of the steel beam: a Steel-CAD program will handle its whole geometry and also the machining, while only the centre line will be considered by the structural analysis program – Figure 3. This aspect is very important in regard to information consistency. Non interpreted data must not be lost. More detailed comments can be found in (Haller, Hörenbaum, Osterrieder and Saal 2004).

Figure 3



Different views

2.2 Definition

The idea of product modelling appeared already in the mid-eighties, especially for electrical and mechanical engineering as well as for shipbuilding. In this context, the International Organisation for Standardisation (ISO) issued a standard (ISO 10303) to harmonise the definition and application of product models. It provides a procedure to elaborate a product model and an object-oriented programming language to define it, called EXPRESS. Because of the consistency problem mentioned in 2.1, the methodology to construct the interface is of first-order and can be divided in 3 fundamental steps:

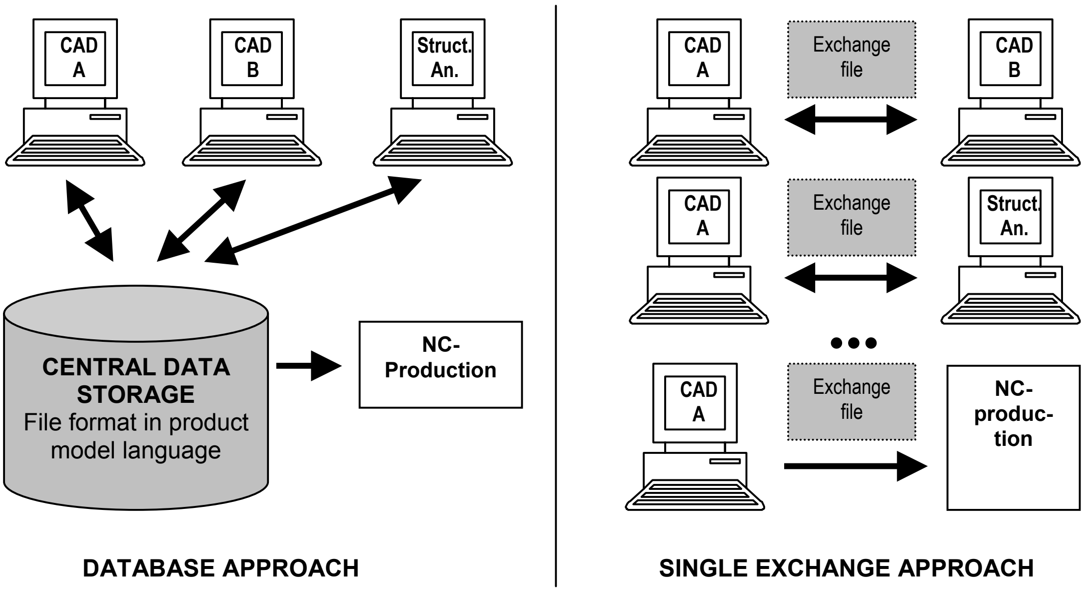
a. Determination of application scenarios, i.e. which project partners will share information.

b. Definition of the exchange contents, i.e. what information shall be exchanged. This also includes the analysis of the specific views – see Figure 3.

c. Formulation of the relevant objects with a neutral language – for instance EXPRESS.

The quality and thus the applicability of a product model is dependant on the model architecture resulting from the analysis of the above listed points. Further it is important to consider how the exchange of data will be performed. There are two possible application methods of product models shown in Figure 4. The database approach is the consequential application of the product modelling idea and aims for collecting all information in a unique central database. This is the only way to guarantee data consistency. Though, it poses problems in view of data management due to the volume of accruing information and version management due to parallel planning. The single exchange approach uses the product model language for single exchange steps. This does not mean inevitable data loss, provided that the used software does ignore non compiled information but keeps it. This method poses consistency problems, but allows data sharing in a simple and immediately applicable way: the central information management is the CAD system, and after exchanges with structural analysis programs or other CAD applications, the data are transferred to NC-production. This concept does fit for the engineer's view in the steel construction domain.

Figure 4



application methods of product model interface in practice

After analysis of the above mentioned points and elaboration of the product model, the latter has to be implemented in the software and the conformity of those implementations has to be checked (Hörenbaum and Saal 2003)

3 Product models in the steel construction domain

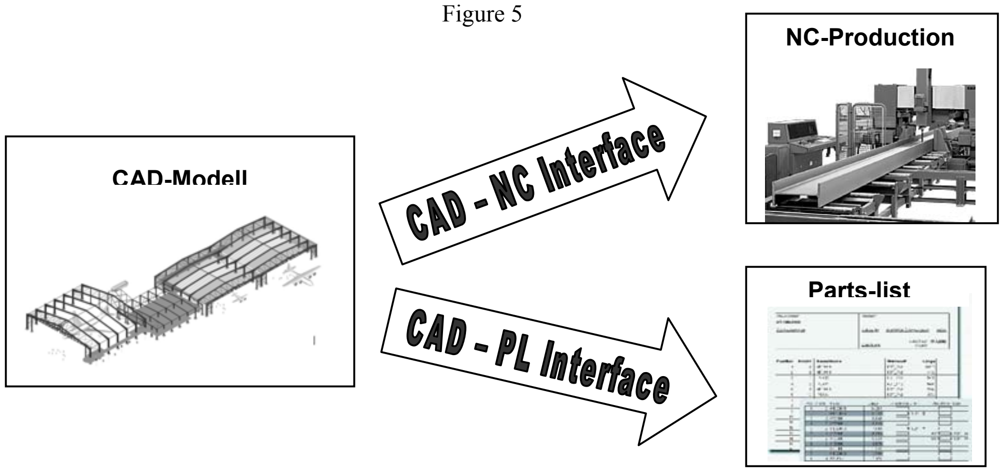
3.1 Preliminary note

Due to its high standardisation potential the steel construction domain is particulary appropriated for the use of product models. As a matter of fact most of the employed basic building parts are conform to a standard, e.g. profiles or bolts. Further, most of the finished building parts were prefabricated in the factory and are only assembled on the building site. Their production is automated in whole or in big part, performed by NC-machines. Many steel construction associations took this situation in account and recognized the benefits of product modelling. Hence, several product models for the sector were developed. Within the scope of this paper, the investigations will on one hand focus on the interfaces distributed by the German steel construction association (DStV [1)]), i.e. the NC-Interface (DStV-1 2002), the parts-list (PL) interface (DStV-2 2002) and the product interface steel construction (PSS[2)]) (DStV-3 2002). Those exchange standards find large application all over the world and are publicly available. The Industry Foundation Classes (IFC) product model will be presented in the next section. It does not dispose of all needed steel construction resources yet, but shall be extended. The PSS will be described in detail because it is used for this extension. For the sake of completeness, another product model for steel construction domain has to be mentionned: the CIMIntegrationStandards (The steel construction institute 2000). Its scope is very large, but the interface is not publicly available. Therefore, at least in Germany, it is not used.

3.2 Basic Interfaces

In a first step, the DStV recognised the advantages of interfaces for highly automated processes in steel construction, i.e. CAM applications. Therefore two unidirectional interfaces were developed, the first is the standard description for steel structure pieces for numerical controls (NC) (DStV-1 2002), the other for transfer of parts-lists from CAD-models (DStV-2 2002). Both are relatively rudimentary in comparison with the actual state of the art, but they feature the two principal characteristicas of product models: they are totally neutral, i.e. not limited to one software, and open to the public. Their application scenarios are shown in Figure 5.

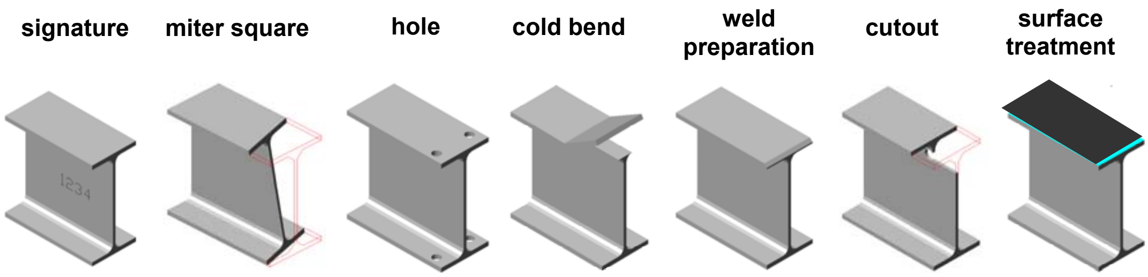
Figure 5



Application scenarios of the NC- and the parts-list interfaces of the DStV

The standard description for steel structure pieces for the numerical controls (NC) (DStV-1 2002) is a standard interface for the geometrical description of steel structure pieces for the post-processors with numerical control. As shown in Figure 6 the covered machining features are holes, internal and external contours with or without welding preparation, numeration, marks by powder or by punch, special cuts and bended parts. The second interface allows the overtaking of part-list information of the CAD model via a filter function which suspends geometric data. Actually those interfaces are implemented in numerous steel CAD-programs and find widespread application. Therefore they are still enhanced by the IT working group of the DStV. Actually the product model allows handling of both NC-data and parts-lists in one exchange file. A formulation in XML-language is also in progress, which shall open the internet as an exchange platform.

Figure 6



NC machining features

3.3 The Product Interface Steel Construction

3.3.1 History

After rationalisation of the data flows towards production, the next purpose of the steel construction industry was to allow compatibility between all actors involved in the structural design, also in view to automate planning steps. The investigations performed within a research program showed the necessity of integrated data flows, i.e. a superordinate product model – the idea of the PSS was born. The first version of the steel construction product model which became the PSS was then developed at the universities of Karlsruhe and Stuttgart (Haller 1994). In accordance with its targets, the DStV decided to support as well its enhancement and its distribution. Actually the PSS is implemented in most of the CAD and structural analysis applications and is the only global steel construction product model which finds application in practice. Its main handicap is its limitation to the steel construction domain. Therefore, in view of further development, the IT working group of the DStV decided to privilege the implementation of the PSS features into the Industry Foundation Classes presented in section 4 rather than keeping an isolated application for the steel construction domain.

3.3.2 Scope and architecture

The target of the PSS is to model all structural "activities" of the steel construction domain. The main application scenarios are the exchange of data among and between CAD and structural analysis programs as well as the transfer of production information similar to the interfaces presented in 3.2. The model architecture is kept quite simple and divided in three main parts providing language resources for building conception, detailing of the steel structure and structural analysis. Attributes are defined directly in entities or by direct referenciation, inheritence is not used. Basic properties like geometry are normally defined implicitly or feature-based (Saal and Haller 1994). All relationships are oriented towards the way of thinking of the enginner. The result is a compact and clear model, easy to implement and use. Figure 7 shows the architecture and the implementation domains of the PSS. The latter represent application scenarios of the interface, i.e. concrete exchange cases in practice. This facilitates partial implementation of the model into the software. With respect to the application of single exchange steps according to section 2.2, partial implementation may be sufficient. The modeled objects of the current version can be spread in 7 groups:

a. general data: geometry resources, building information, material, construction grids…

b. concept data: positionning of the structure, building components…

c. structural analysis model: abstraction of the real building geometry in a mechanical model.

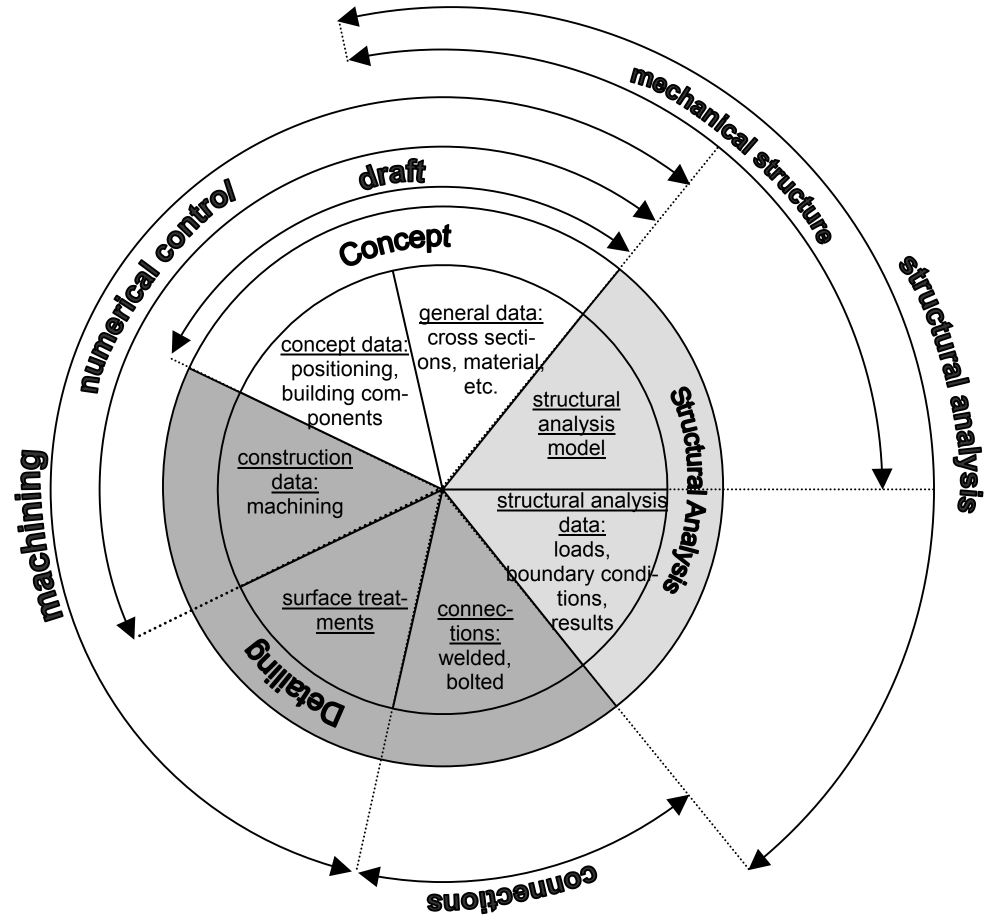
d. structural analysis data: additional structural analysis information like loads, boundary conditions, etc.

e. construction data: machining features on building elements (as in Figure 6).

f. surface treatments: treatments on defined surfaces of building elements.

g. connections: description of all types of bolted, welded or glued connections.

Figure 7



PSS model architecture and implementation domains

The above mentionned implicit definition of normalised parts is made possible by the use of normalised definitions (DStV 2003). The product model is oriented towards the production in factory. Therefore it was also developed to represent partial production steps, i.e. different states of building elements. For example, the definition of a cold bend associates the finished bended product with its initial form. This concept will be discussed in regard to the integration of the PSS into the IFC.

4 Modelling the whole A/E/C Domain: the Industry Foundation Classes

4.1.1 History

Domain restricted product models do also exist for other construction domains, but, such as the PSS, they are not easily extensible to other sectors. In regard to the mentioned diversity of project partners (Figure 1), the ideal concept of a product model in A/E/C industry would allow to link all worldwide used building software. The International Alliance for Interoperability was founded 1995 in the USA and short time after there were branches in Germany, UK, France, Scandinavia, Singapore, Japan, Korea and Australia. Its purpose is to develop such an overall construction product model: the Industry Foundation Classes (IFC). The actual version of the IFC Platform (International Alliance for Interoperability 2003) already provides definitions for objects of architecture, facilities management, technical and interior building equipment as well as structural analysis . Because of its approach, the IFC product model acquired the status of an ISO Standard (ISO 16739). The DStV is striving for a steel construction and structural analysis extension of the IFC. The integration of those features is performed within the ST-4 extension project[3)] divided in two steps:

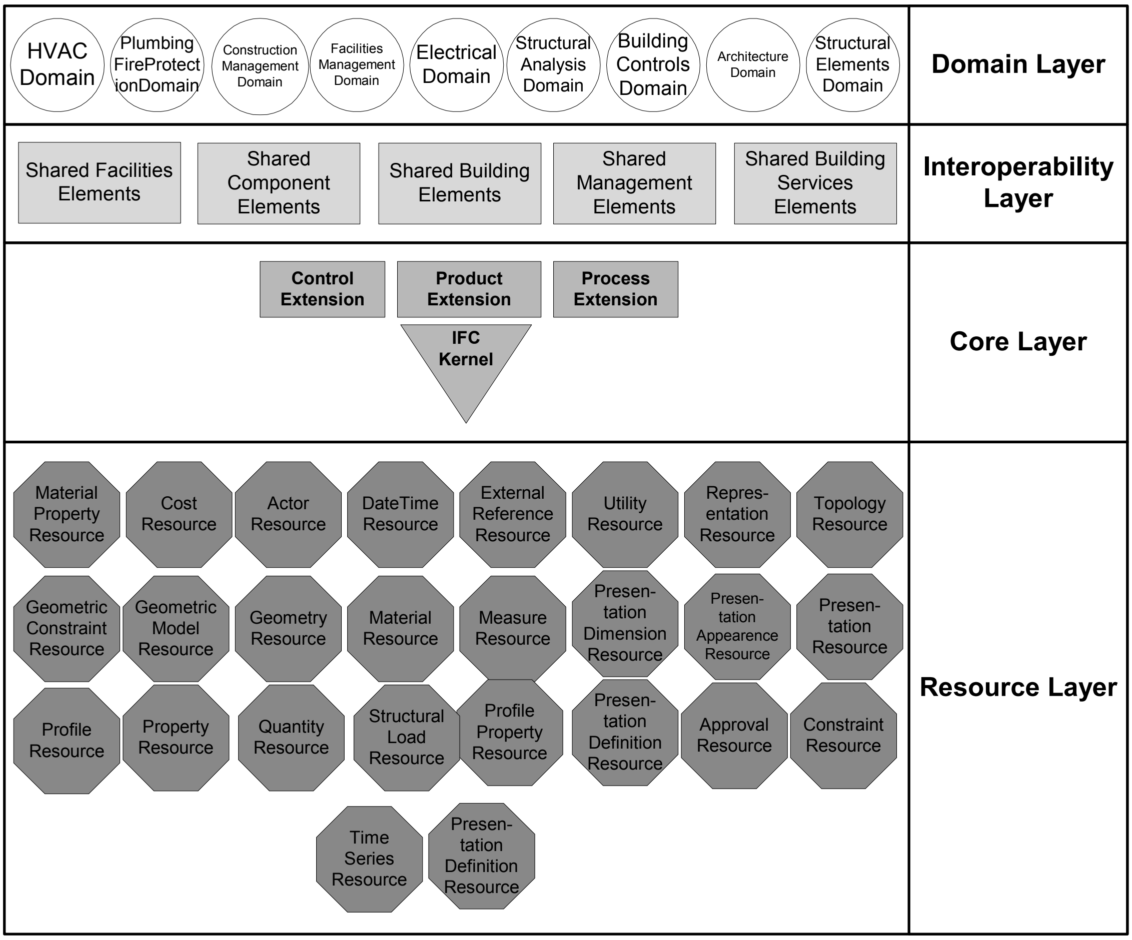
- ST-4.1: extension with the basic and drafting steel construction resources and structural analysis part.
- ST-4.2: extension with the steel detailing part. This is a running project led by the Lehrstuhl für Stahl- und Leichtmetallbau of the Universität Karlsruhe (TH).

Parallel the structural extension also comprises a pre-cast concrete part (ST-3 project) – which is already integrated in the IFC (Karstila and Serén 2004) – and a timber construction part (ST-5 project). The development of the latter is in course and performed by the Lehrstuhl für Statik und Dynamik of the Universität Cottbus. More information can be found at <http://www.statik.tu-cottbus.de>. The IAI also supports the development of an XML-version of the IFC, also with regard to opening the internet as an exchange platform.

4.1.2 Scope and architecture

The model architecture of the IFC is of first order, due to the diversity of modelled domains and the complexity of the relationships between them. Figure 8 shows the diverse modelled construction sectors and the modular architecture of the IFC. To allow such complex entanglements between the numerous fields of activity covered by the IFC, the model is clearly structured (class levels) and the relationships between objects are strictly ruled (gravity principle). The objects are the more abstract, the lower they are defined in this schema. The resource layer provides basic definitions like units, geometrical objects, etc. The core layer connects all other modelled domains with all basic semantics like objects, relationships and attributes. Domain layers are partial models for delimited application areas and are connected with the core layer through an intermediate layer: the interoperability layer. In one layer, objects with a comparable purpose are grouped in classes. The gravity principle corresponds to the top-down approach of the whole model. Basic objects are detailed by decomposition. Generic data structures are inherited from the kernel to the domain objects, and referencing is also ruled by this principle. Classes defined in a layer may reference other classes in the same layer or from lower layers. This secures the consistency of the model. Hence, objects defined in a domain layer are more detailed specifications of the more general objects of the underlying layers. This modular structure of the architecture allows an independent and flexible development of partial models while basic compatibility is guaranteed by the unchanging kernel and the imposed upward compatibility of the model. Data exchange can occur on a high level between two similar software applications with high degree of detailing or between two different domains with less information density. The IFC product model is oriented towards compatibility within the whole building project. Specific considerations of one planner are not modeled. This is done in favour of consistency, but implicates the representation of finished products. A detailed description of all features can be found on the internet (International Alliance for Interoperability 2003). Within the scope of this paper the focus shall be set on definitons which may be relevant for the steel construction extension. Within the ST-4.1 project the current version of the IFC was extended with basic steel construction resources for material with its specific properties, geometry with parametrised profile definitions. Further steel structure conceptual and structural analysis entities were added. Hence points a. to d. of the enumeration in section 3.3.2 are already covered. The ST-3 precast concrete extension also provided relevant entities for connections. Diverse fastener types were defined and the building element "plate" was introduced. Those entities are more important in the steel construction domain.

Figure 8

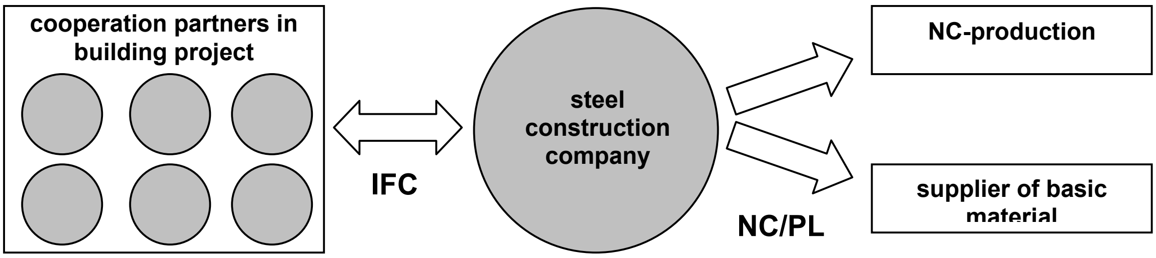


The IFC model architecture

5 Steel detailing extension of the IFC

Within the scope of this paper, the focus shall be set on the strategy for ST-4.2 extension. The steel construction detailing can be considered as a part of the structural extension of the IFC, besides the structural analysis, the timber and the precast concrete extension. Therefore no specific steel construction classes will be implemented into the model. The objects will be integrated in already existing structural classes, i.e. *IfcSharedComponentElements* on the interoperability layer and *IfcStructuralElementsDomain*, which were introduced by the ST-3 project. The main tasks are to provide resources for connections and machining, which are detailed such that they satisfy for the requirements of the steel construction domain. The existing definitions of connections, especially with mechanical fasteners are not sufficient yet and have to be extended. Machining features have to be created. Because of the restriction explained in section 4.1.2, only works which can be associated with the finished product shall be implemented, i.e. cutouts, holes, signatures and surface treatments. The bending process will not be allowed to be represented. As a matter of fact, the purpose of the IFC is an overall exchange with all project partners. On one hand, if a member is visibly curved, other domains will not be able to handle the object transformation, e.g. a member curved by the fabrication process connot be related to the original linear member. On the other hand, a member may be pre-bend to be straight under dead-load. In this case the finished product is curved, but non specific applications would not be able to treat it, and thus this might lead to consistency problems. It has to be mentioned, that this kind of processing only concerns the fabricator and is unidirectional. Therefore, the application method of interfaces shown in Figure 9 is proposed for steel construction domain. As the NC- and parts-list interfaces presented in section 3.2 are implemented in most of the computer applications, this would not mean additional work and not be in contradiction with the product modelling idea.

Figure 9

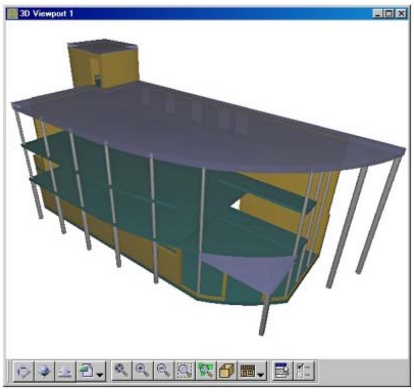


Application of product models in steel construction domain

6 Advantages

The advantages of an extension of the IFC to steel construction or even all areas of structures are effective in both directions. Each enhancement of the IFC standard brings it nearer to its goal. On the other hand the steel construction domain will be able to take part in the exchange processes over the whole building project. For the german steel construction industry the extension is also important because of the international aspect of the IFC interface. In regard to the actual globalisation in all industry sectors, this is a very important aspect. Actually the IFC will allow structural data exchange with all concerned partners, and interdependencies can be checked. For example openings in a building can have incidence on multiple project partners, like the architect, the structural engineer, the performing maintenance group – e.g. steel constructor –, as well as all internal building equipment planners (electric, HVAC, etc. installation)… A global exchange file with objects of all planners in IFC format allows a better control of the building project. In this way building elements can be filtered out by diverse criteria, e.g. type or author. Planning inconsistencies can be located easier, e.g. collisions. Because of unique identities of objects, changes can be detected without much efforts. Other reliefs of the IFC could be enumerated, but briefly they concern all tasks where interaction between diverse domains occurs. Figure 10 shows the load bearing elements of a building, extracted from an IFC file containing the whole project information with (SOLIBRI, 2004). Due to the actual economic situation, numerous steel construction companies have enlarge their activity to “turnkey”-construction, and often operate as general contractor. Thus they have to work in different areas of activity and handle data from it. They may also be responsible for the project coordination. Therefore it is obvious that, even for the short term, the availibility of a product model which extends over a lot of domains is particullary useful.

Figure 10



Load bearing structure extracted from whole building model (SOLIBRI 2004)

The real potential of the IFC will reveal itself in the long run. As a matter of fact, beside the development of product models, there are three other technologies which get more and more important. First, there are the internet based project management systems. Their concept is to provide a virtual workspace for the project partners, where all information and processes are collected and documented. Further many research activities focus on multi-agent environments. A software agent is an autonomous software system, which can analyse situations and decide to react on it or not. The software agent could be able to perform some tasks in the building project environment instead of project actors. Finally, the use and the performance of communication systems is growing rapidly. Internet availabilty in companies, high data transfer rates and peer to peer networking can be mentionned as keywords. With the idea to combine those technologies, an optimum project processing could be possible. The IFC product model would provide overall data compatibility within the project. Then, information management and distribution between the involved actors is allowed by project management systems in combination with peer-to-peer networking. Many tasks of basic checking and information distribution could be performed by software agents, e.g. automatic detection of changes and notification to concerned planners. All project processes could gain in consistency, and thus time and money could be saved. Losses due to ineffiencies are estimated to amount up to 40% of all project costs. This shows how important a progress like described before may be. The basic key for such an optimisation is the overall compatibility provided by the IFC.

7 Conclusion

It has been shown that good working product models already exist for the steel construction domain. Every day they support the specific planning and production tasks of this building sector. But with regard to the high time and cost pressure in the building industry, data compatibility over the whole A/E/C domain is required. This is the idea of the IFC, which will provide detailed domain specific resources as well as coarse resources for sharing data between diverse areas of activity. The DStV recognised the potential of the IFC product model and succeeded in establishing its steel construction and structural extension with the PSS abilities as benchmark. On one hand, this integration secures an up-to-date position of the steel construction companies in the building industry. On the other hand covering of all building sectors is required for the use of all efficiency and potential of the IFC. Actually an overall product model allows easier checking of planning interferencies like collisions between diverse actors involved in a building project.In the future, the IFC may become the basis for highly integrated and optimated building processes. Finally it has to be pointed out, that even if all domains are represented by a product model no progress is performed unless the interfaces are implemented in the software.

8 Endnotes

1) DStV is the abbreviation for Deutscher Stahlbauverband, the German steel construction association.

2) The abbreviation PSS for the product interface steel construction comes from its German name Produktschnittstelle Stahlbau.

3) More detailed information concerning the ST-4 extension can be found at the homepage of the technical University of Dresden <http://cib.bau.tu-dresden.de/main.html>. Relevant publications are (Hörenbaum 2002), (Hörenbaum, Liebich and Weise 2001), (Hörenbaum and Liebich 2002) and (Katranuschkov, Liebich and Weise 2002).

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